Factors Predicting Change in Pelvic Posterior Tilt After THA

TAKAYUKI KYO, MD; ICHIRO NAKAHARA, MD, PhD; HIDENOBU MIKI, MD, PhD

Abstract

Full article available online at Healio.com/Orthopedics. Search: 20130523-20

In total hip arthroplasty, steep cup inclination should be avoided because it increases the risk of edge loading. Pelvic posterior tilt should be carefully monitored because it increases cup inclination and anteversion, leading to edge loading or impingement.

The authors evaluated how much the pelvic tilt angle changes from the supine position referenced in planning for cup orientation preoperatively to the standing position 1 year after total hip arthroplasty ($\Delta_{\text{ref}}$). The pelvic tilt angle was measured in 124 patients who underwent total hip arthroplasty due to osteoarthritis, and the mean $\Delta_{\text{ref}}$ was $-9.5^\circ \pm 5.3^\circ$ (range, $-23^\circ$ to $5^\circ$). Preoperative compression fractures, spondylolisthesis, and disk-space narrowing were predictive of increased pelvic posterior tilt after total hip arthroplasty. The authors mathematically calculated how much change in pelvic posterior tilt was clinically possible with the original cup alignment, which ranged from $40^\circ$ to $45^\circ$ of radiographic inclination and $0^\circ$ to $30^\circ$ radiographic anteversion to more than $50^\circ$ of inclination. Even if the maximum posterior tilt ($23^\circ$) occurred, no edge loading would occur in almost half of those original cups.

Surgeons should aim for $40^\circ$ of inclination. When the original cup inclination was $40^\circ$, edge loading was prevented. Edge loading caused by steep cup inclination can be prevented by adjusting the cup orientation to account for predicted pelvic tilting, but spinal alignment must also be considered because lumbar kyphosis can increase postoperative pelvic posterior tilt.

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The authors have no relevant financial relationships to disclose.

The authors thank Katharine O’Moore-Klopf, ELS, for providing the professional English-language editing for this article.

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doi: 10.3928/01477447-20130523-20
Steep cup inclination must be avoided in total hip arthroplasty (THA) because it increases the risk of serious complications related to edge loading, such as polyethylene wear, liner failure of ceramic-on-ceramic bearings, and high metal-ion concentration and adverse reactions to metal debris for metal-on-metal bearings.\textsuperscript{1-4} However, cup orientation is influenced by pelvic alignment.\textsuperscript{5,6} Posterior pelvic tilt is especially important because increasing cup inclination and anteversion can lead to edge loading or impingement.

It has become possible for surgeons to use 3-dimensional (3D) templates in preoperative planning for THA. When using such templates, a pelvic coordinate system is necessary for planning the cup orientation, and it is generally constructed from a reference pelvic plane, which is determined by picking several reference points on the surface of a 3D pelvic model in preoperative planning software. Historically, the anterior pelvic plane was initially used as a reference and was defined by 3 reference points: the left and right anterior superior iliac spines and the midpoint of the left and right pubic tubercles. Although the anterior pelvic plane was considered to be superimposable on the horizontal plane in the supine position and on the vertical plane in the standing position, a large degree of interpatient variation exists in the anterior pelvic plane.\textsuperscript{5,6} The functional pelvic plane in either the supine or standing position (the supine functional pelvic plane and the standing functional pelvic plane, respectively) is normally used as the reference pelvic plane (Figure 1).\textsuperscript{5,7} Each is created by rotating the anterior pelvic plane around the horizontal axis of the pelvis by the pelvic inclination in the supine position or the standing position measured by preoperative computed tomography (CT) or radiographs. Although the standing functional pelvic plane corresponds with the position of the pelvis in most activities of daily living, the current recommendation for acetabular cup orientation is based on previous data using the supine functional pelvic plane. Several clinical reports have concluded that surgeons should avoid steep cup inclination in supine anteroposterior (AP) radiographs to prevent edge loading.\textsuperscript{1-4} Furthermore, simulation studies have been performed since the late 1990s to calculate the optimal cup orientation for avoiding prosthetic impingement within the intended hip range of motion (ROM).\textsuperscript{8-11} An inclination of 40° to 45° and anteversion based on the combined anteversion theory have been recommended for cup orientation in THA, and the concept of combined anteversion was also proposed in a similar simulation study.\textsuperscript{11} In these studies, hip ROM measured in the supine position was commonly used as the intended hip ROM.\textsuperscript{12} In addition to the advantages of using the supine functional pelvic plane already mentioned, some authors have recommended using the supine functional pelvic plane as the reference plane for preoperative cup orientation planning; the supine pelvic tilt angle is a reasonable approximation of the standing pelvic tilt angle because the change in pelvic inclination between supine and standing positions is small in most patients (within 10° in 83% to 90% of patients).\textsuperscript{5,7}

However, when the supine functional pelvic plane is used as reference, it is a concern from the point of view of prevention of edge loading whether the pelvic tilt angle chosen in preoperative planning is maintained in the standing position for a long time after THA. Taki et al\textsuperscript{13} reported that the change in pelvic posterior tilt in the standing position appeared to plateau 1 year after THA. Thus, it is necessary to know how much the pelvic tilt angle will change from the supine position referenced for cup orientation planning to the standing position at 1 year after THA. However, no detailed reports have been published of how much change occurs in the same patient, although Nishihara et al\textsuperscript{7} reported that the mean change in preoperative pelvic posterior tilt from the supine to the standing position (preoperative positional change in pelvic tilt) was 2°±6.4° and that the mean change in pelvic posterior tilt in the standing position before
Factors Predicting Change in Pelvic Posterior Tilt after THA

JUN 2013 | Volume 36 • Number 6

Factors Predicting change in Pelvic Posterior tilt after THA | Kyo et al

and at 1 year after THA was $2^\circ \pm 7.5^\circ$. Taki et al\textsuperscript{13} reported that these values were $4^\circ \pm 5.0^\circ$ and $3.9^\circ \pm 6.2^\circ$, respectively.

The purposes of the current study were to evaluate the change in the pelvic tilt angle preoperatively and 1 year after THA and to determine the factors that contributed to the change so surgeons can estimate the risk of edge loading using the posterior pelvic tilt.

**MATERIALS AND METHODS**

**Patients**

One hundred twenty-four patients (116 women and 8 men) with a mean age of 66 years (range, 38 to 85 years) who underwent primary THA at the authors’ hospital for osteoarthritis (OA) between April 2009 and September 2010 were included. Of those, 119 patients had OA due to dysplasia, 4 had primary OA, and 1 had rapidly destructive coxarthropathy. Of the 119 patients with OA due to dysplasia, 72 had grade 1 OA, 42 had grade 2, and 5 had grade 3 according to Crowe’s classification. Bilateral OA was present in 56 patients; of these, 25 had already undergone contralateral THA before presenting to the current authors’ institution.

The authors performed preoperative planning with a 3D template and the planning module of a navigation system (Stryker Hip Navigation System 1.0; Stryker-Leibinger, Freiburg, Germany) based on CT scans. In preparation for planning, CT scans were obtained from the pelvis to the knee joint and were transferred into the planning module. First, an anterior pelvic plane was constructed that was defined as a plane, including the bilateral anterior iliac spines and the midpoint of the bilateral pubic tubercles as reference points. The x-axis of the pelvic coordinate system based on the anterior pelvic plane was parallel to the line including the right and left anterior superior iliac spines, the y-axis was perpendicular to the anterior pelvic plane, and the z-axis was perpendicular to the x- and y-axes. The supine functional pelvic plane was created by rotating the anterior pelvic plane around the x-axis until the anterior pelvic plane was parallel to the knee joint and were transferred into the planning module. First, an anterior pelvic plane was constructed that was defined as a plane, including the bilateral anterior iliac spines and the midpoint of the bilateral pubic tubercles as reference points. The x-axis of the pelvic coordinate system based on the anterior pelvic plane was parallel to the line including the right and left anterior superior iliac spines, the y-axis was perpendicular to the anterior pelvic plane, and the z-axis was perpendicular to the x- and y-axes. The supine functional pelvic plane was created by rotating the anterior pelvic plane around the x-axis until the anterior pelvic plane was parallel to the CT table in the planning module. With regard to the femoral coordinate system, the retrocondylar plane, which included 3 reference points (the most posterior point of the proximal femur and the medial and lateral posterior condyles), was used as a reference plane. The authors planned cup and stem orientation using a 3D template. Regarding the target cup angle, the authors referred to the simplified combined anteversion theory in the literature.\textsuperscript{14} All surgical procedures were performed from the posterolateral approach using the navigation system.
The following THA components were used: for acetabular cups, the authors used the Trident (Stryker, Mahwah, New Jersey) in 51 patients, the Adept (Finsbury, Leatherhead, United Kingdom) in 69, the CONSERVE Plus (Wright Medical Technology, Arlington, Tennessee) in 2, and the Trilogy (Zimmer, Warsaw, Indiana) in 2. For femoral stems, the authors used the CentPillar (Stryker) in 92, the Accolade (Stryker) in 14, the Omnifit J-EON Plus (Stryker) in 9, the S-ROM (DePuy, Warsaw, Indiana) in 5, the PROFEMUR TL (Wright Medical Technology) in 2, and the PROFEMUR R (Wright Medical Technology) in 2. All patients began full weight-bearing movement on postoperative day 1 and received standard rehabilitation care. They were discharged 2 to 3 weeks later and could walk with or without a cane. By 1 year postoperatively, no patients had experienced serious postoperative complications, such as dislocation, infection, or mechanical loosening.

**Measurement of Pelvic Tilt Angles**

Pelvic tilt angle determined using the radiograph-CT model-matching method reported by Nishihara et al17 (Figure 2). All patients had anteroposterior (AP) radiographs of the pelvis in the supine and standing positions 2 weeks preoperatively and approximately 1 year after THA (mean, 12 months; range, 10 to 14 months). The vertical diameter of the pelvic foramen (A) divided by the maximum horizontal diameter of the pelvic foramen (B)—the A:B ratio—was calculated for the AP radiographs of the pelvis in the supine and standing positions. Value A was defined as the distance between the line connecting the inferior bilateral margins of the sacroiliac joint and the superior margin of the pubic symphysis, and value B was defined as the maximum horizontal diameter of the pelvic foramen. In the planning module of the navigation system, the pelvic coordinate system based on the anterior pelvic plane was first created on the 3D pelvic model. The AP view of the 3D pelvic model was shown by projecting it onto the x-z plane of the pelvic coordinate system. The vertical diameter of the pelvic foramen (A’) and the maximum horizontal diameter of the pelvic foramen (B’) for the AP view of the pelvic model were defined, and the authors rotated the pelvic model around the x-axis of the pelvis until the A’:B’ ratio matched the A:B ratio measured on the AP radiograph in the supine and standing positions. The rotating angles around the x-axis were defined as the pelvic tilt angles in the supine and standing positions. Positive values for pelvic tilt indicated an anterior tilt of the anterior pelvic plane. The changes in the pre- and postoperative pelvic tilt angle from the supine to the standing position were named Δpre and Δpost, respectively. The change of the pelvic tilt angle from preoperatively to 1 year postoperatively in the supine and standing positions were named Δsupine and Δstanding, respectively. The change in the pelvic tilt angle from preoperatively to postoperatively in the standing position was named Δref (Figure 3).

**Predictive Factors**

For each patient, the authors recorded age; preoperative thoracic and lumbar alignment; the existence of a compression fracture, spondylolisthesis, or disk-space narrowing in the lumbar spine preoperatively; and the preoperative hip flexion contracture angle for the operated side as candidates for predictive factors for a change in pelvic tilt. Using the Cobb method and preoperative lateral spine radiographs, the authors defined thoracic alignment as the angle between the superior endplate of T4 to the inferior endplate of T12, and lumbar alignment as the angle between the inferior endplate of T12 to the superior endplate of S1.15,16 For those angles, lordosis was expressed as a positive value and kyphosis as a negative value. A compression fracture was defined as follows: the height of the anterior (A) and posterior (P) edge of the vertebral body were measured on lateral radiographs of the lumbar spine; a compression fracture existed when the A/P value was less than 0.85.17 Spondylolisthesis was defined as any grade greater than 1 using the Meyerding criteria.18 Disk-space narrowing was defined as a grade greater than 1 on the semiquantitative grading scale reported by Lane et al.19 The preoperative position of the operated hip with the patient in the supine position was calculated from preoperative CT

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**Table 1**

<table>
<thead>
<tr>
<th>Posture</th>
<th>Preoperative Angle</th>
<th>Postoperative Angle (1 y After THA)</th>
<th>Change from Pre- to Postoperative</th>
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<tr>
<td>Supine position</td>
<td>3.2±8.2 (−18 to 25)</td>
<td>0.1±9.1 (−25 to 22)</td>
<td>Δsupine −3.1±3.6 (−13 to 5)</td>
</tr>
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<td>Standing position</td>
<td>−3.6±11.2 (−34 to 25)</td>
<td>−6.1±10.9 (−35 to 25)</td>
<td>Δstanding −2.7±5.3 (−14 to 13)</td>
</tr>
<tr>
<td>Change from supine to standing position</td>
<td>Δpreoperative −6.8±5.1 (−21 to 9)</td>
<td>Δpostoperative −6.4±4.4 (−19 to 4)</td>
<td>Δref −9.5±5.3 (−23 to 5)</td>
</tr>
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</table>

*Abbreviations: Δref, change in the pelvic tilt angle from before surgery in the supine position to after surgery in the standing position.*
scans as the relative angle between the pelvic coordinate system based on the supine functional pelvic plane and the femoral coordinate system based on the retrocondylar plane. The neutral position was defined as the position in which the x-, y-, and z-axes of the femoral coordinate system are parallel to the x-, y-, and z-axes of the pelvic coordinate system, respectively. The hip flexion contracture angle was the flexion-extension element of the preoperative hip position in the supine position.

**Statistics**

Using multiple logistic regression analysis (StatView, version 5.0; SAS Institute, Cary, North Carolina), the authors investigated factors that predicted that the Δref was less than −10°. P values of less than .05 indicated statistical significance using stepwise selection.

### RESULTS

#### Pelvic Tilt Angle

Pelvic tilt angles are shown in Table 1. Mean preoperative pelvic tilt angles in the supine and standing positions were 3.2°±2.9° (range, −18° to 25°) and −3.6°±11.2° (range, −34° to 25°), respectively. Mean values for postoperative (1 year after THA) tilt in the supine and standing positions were 0.1°±9.1° (range, −25° to 22°) and −6.1°±10.9° (range, −35° to 25°), respectively. The respective mean values for Δpre and Δpost were −6.8°±5.1° (range, −21° to 9°) and −6.4°±4.4° (range, −19° to 4°), whereas the respective mean values for Δsupine and Δstanding were −3.1°±3.6° (range, −13° to 5°) and −2.7°±5.3° (range, −14° to 13°). Mean Δref was −9.5°±5.3° (range, −23° to 5°). Thirty-five (28%) patients had a Δpre of less than −10°, twenty-eight (23%) had a Δpost of less than −10°, and 67 (54%) had a Δref of less than −10°.

#### Predictive Factors

Age and lumbar alignment were statistically significant predictive factors of a Δref of less than −10° (Table 2). The odds ratios were 1.05 (95% CI, 1.00 to 1.09) for age and 1.06 (95% CI, 1.03 to 1.10) for lumbar alignment.

The predictive factors for a Δref of less than −10° for the lumbar spine are shown in Table 3. The odds ratio was 8.84 (95% CI, 1.66 to 47.12) for a compression fracture, 9.88 (95% CI, 2.94 to 33.18) for spondylolisthesis, and 4.73 (95% CI, 2.01 to 11.12) for disk-space narrowing.

### DISCUSSION

To prevent edge loading over the long term after THA, it is necessary to estimate the maximum possible change in pelvic tilt angle in the same patient from the supine position at preoperative planning to the standing position at 1 year after THA (Δref). This value can be obtained from the upper limits of the 95% CI prediction interval (mean ± 2 SD) found in earlier studies in which the change in the preoperative posterior pelvic tilt angle from the supine to the standing position was 14° to 14.8° and the posterior change of the pelvic angle in the standing position from before THA to 1 year after THA was 16.3° to 17°. Those findings are similar to the maximum posterior changes in the current study of 21° and 14°, respectively. Therefore, if a patient meets these maximum changes in pelvic tilt, the Δref is estimated from those data to be 35°. However, the authors found that the Δref was a maximum of 23° in the same patient.

Using the following formula, the authors calculated how much change in pelvic posterior tilt was clinically possible with the original cup alignment, which ranged from 40° to 45° of radiographic inclination and 0° to 30° of radiographic anteverision to greater than 50° of inclination (Table 4).

In the formula, C is the original radiographic cup inclination, δ is the posterior pelvic tilt angle, N is the normal unit vector to the opening plane of the cup in the original position, N′ is the normal unit vector to the opening plane of the cup after posterior tilt (δ) from the original
cup position, CA’ is the radiographic cup anteverision after posterior tilt (Δ) from the original cup position, and CI’ is the radiographic cup inclination after the posterior tilt (Δ) from the original cup position.

\[
\begin{align*}
M_x &= \begin{bmatrix} 1 & 0 & 0 & 0 \\
0 & \cos C A & -\sin C A & 0 \\
0 & \sin C A & \cos C A & 0 \\
0 & 0 & 0 & 1 \end{bmatrix} \\
M_y &= \begin{bmatrix} \cos C I & 0 & \sin C I & 0 \\
0 & 1 & 0 & 0 \\
-\sin C I & 0 & \cos C I & 0 \\
0 & 0 & 0 & 1 \end{bmatrix} \\
M_p &= \begin{bmatrix} 1 & 0 & 0 & 0 \\
0 & \cos \Theta & -\sin \Theta & 0 \\
0 & \sin \Theta & \cos \Theta & 0 \\
0 & 0 & 0 & 1 \end{bmatrix} \\
N &= M_y \cdot M_x \cdot (0, 0, -1) \\
N’(x’, y’, z’) &= M_p \cdot N \\
CI’ &= \arctan(-x’/z’) \\
CA’ &= \arccos(\sqrt{x'^2 + z'^2})
\end{align*}
\]

This calculation shows that if a 35° pelvic posterior tilt angle exists after THA, edge loading will be a concern for almost all of those original cups. However, the actual maximum posterior pelvic tilt (ΔRef) was 23°. Therefore, no edge loading will occur in approximately half of those original cups. Furthermore, the authors recommend that surgeons should aim for 40° of inclination because the safety range of the anteverision angle was wider when the cup inclination angle was closer to 40° than to 45° (Table 4). When the cup inclination is 40°, edge loading will be prevented even if maximum posterior tilt occurs.

This study had some limitations. First, with regard to patient selection, the candidates for the study were patients who had undergone THA because of OA, not including those with osteonecrosis or rheumatoid arthritis. If the authors had included patients with osteonecrosis or rheumatoid arthritis, they might have obtained different results. With regard to another problem in patient selection, previous reports documented that the degree of pelvic posterior tilt depended on patients’ ages. The mean age in the current study (66 years [range, 38 to 85 years]) was relatively old compared with populations in previous reports. If a surgeon performs THAs in older patients, the maximum angle of the pelvic posterior tilt may be larger. Moreover, lumbar kyphosis is another factor in increasing pelvic posterior tilt. It has been reported that posterior tilt compensates for posture alignment when there is anterior pelvic tilt and that degeneration of lumbar discs, disk herniation, spondylolisthesis, weak back muscles, osteoporosis, and compression fractures are associated with lumbar kyphosis. The current authors found spondylolisthesis, disk-space narrowing, and compression fractures to be risk factors for pelvic posterior tilt after THA. It is probable that the pelvis unexpectedly tilts posteriorly in the supine position when those conditions occur in the spine in elderly patients. Therefore, to avoid increasing posterior tilt, surgeons should strive for accurate implantation and take the condition of the spine into consideration. Second, another concern exists with pelvic posterior tilt: it may cause prosthesis impingement. If posterior tilt does not change the anatomic hip ROM in regard to the pelvic coordinate system used during preoperative planning, new prosthesis impingement theoretically cannot occur. It has been re-

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Abbreviation: deg, degrees.
ported that immediately postoperatively, the anatomic hip ROM in relation to the pelvic coordinate system based on the supra-pelvic functional pelvic plane is not affected by preoperative positional change in pelvic tilt.\textsuperscript{22} However, it is unclear whether anatomic hip ROM changes over the long term after THA with increasing posterior pelvic tilt, so further research is needed.

**CONCLUSION**

The authors investigated the change in pelvic tilt angle from the preoperative supine position to the standing position 1 year after THA. Even if maximum pelvic posterior tilt occurs after THA, edge loading can be prevented by determining the appropriate cup orientation for implantation by taking the predicted postoperative posterior pelvic tilt into account. The authors also recommend paying attention to the condition of the spine, especially checking for the presence of a compression fracture, to avoid unexpected posterior pelvic tilting.

**REFERENCES**